A LABORATORY TEST SYSTEM FOR PREDICTION OF ASPHALT CONCRETE MOISTURE DAMAGE

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Representative results are described and shown for a practical laboratory test system developed to predict moisture damage in asphalt concrete pavements or to monitor the rate of moisture damage in existing pavements. Moisture-damage predictions are based on the results of tensile strength and tensile E-moduli tests performed on laboratory-fabricated specimens that have undergone freeze-soak and thermal-cycle accelerated moisture conditionings. These test results are compared to similar mechanical tests on pavement cores. The conventional laboratory specimens were made to duplicate pavements that were sampled throughout the United States and that had various levels of moisture damage. Implications of using the test system for predictability of moisture damage are discussed.

•THIS paper summarizes some of the findings of a laboratory system developed to predict moisture damage in asphalt concrete pavements. It also discusses the implications of these findings. Details of the laboratory methods, procedures, and data are in a report by Lottman (1).

MOISTURE DAMAGE AND TESTS FOR PREDICTION

Definition of Moisture Damage and Its Effects

For the purpose of this paper, moisture damage can be defined as the following:

1. Disintegration or deterioration of the intrinsic property of the asphalt concrete layer by entry of moisture that can be measured by the asphalt concrete's loss of mechanical properties, and
2. Loss of pavement serviceability because of increased deflections and higher tensile stresses and strains, which lead to pavement cracking and surface rutting.

Disintegration may take the form of stripping, softening, or swelling, which are often accompanied by loss of stiffness modulus, tensile or compressive strength or both, and aggregate retention properties and by a gain of strain at failure and void space.

Many times both disintegration and loss of serviceability occur simultaneously. However, it is possible to have a disintegrating pavement layer that is caused by moisture damage without pavement performance criteria being affected significantly. In either case, though, the pavement will have to be repaired by using overlays or penetrant additives. Moisture damage can exist in several forms; therefore, a program should be developed to avoid mix problems before pavements are constructed.

Kinds of Moisture-Damage Tests

Moisture-damage tests are applied to 2 different physical forms of asphalt concrete. In the first form, asphalt concrete is in a loose state; only a portion of the aggregate (coated with asphalt) is subjected to static or ultrasonic action in water. The amount of coating that comes off is related to the amount of stripping. Those working in

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fundamental research use this form because "free" conditions of thermodynamics and other scientific approaches can be applied. However, the effects of the amount of coating or coating that comes off eventually have to be measured in the product as compacted asphalt concrete subject to moisture intrusion after field compaction.

The second form, the compacted form, appears to be the favorite of those working with mechanical properties and machines. In certain cases, mechanical properties can be incorporated into pavement layered design theories for performance prediction; in other cases, the mechanical units and related mechanics are not suitable for inclusion. Immersion compression, surface abrasion, Marshall immersion, and tensile split are the tests that use compacted asphalt concrete specimens in dry and wet conditions.

MOISTURE-DAMAGE TEST SYSTEM USED IN THIS STUDY

Comparative Scheme

Pavements were sampled at various locations around the United States. Highway departments sent cores 4 in. (10.16 cm) in diameter, mix materials (aggregate and "equivalent" asphalt representing the pavement), and mix design data (including field sampling data) for pavements that fell into 1 of the following categories:

1. An approximately 5-year-old pavement that shows distress caused by moisture damage, and
2. An approximately 5-year-old pavement that does not show distress caused by moisture damage.

Ten different pavement samples were received for category 1 and 3 for category 2. The locations of many of the samples were selected by severity of climatic temperature according to freezing indexes.

The procedure mechanically and visually tested the cores and compared their data to data from laboratory-fabricated specimens that duplicated the core mixes as closely as possible. The laboratory-fabricated specimens, 4-in. (10.16-cm) in diameter by 2.5-in. (6.35-cm) in thickness made in a kneading compactor, were subjected to specified accelerated moisture conditionings. A comparison of mechanical and visual data between cores and laboratory specimens would show that accelerated moisture conditions are predictive of pavement moisture damage. Therefore, it would be advantageous to use these moisture-damage predictive tests in the laboratory.

Core and Specimen Moisture Conditionings

Pavement cores were tested in a vacuum-saturated condition and in a dry condition (constant weight in desiccator). After testing, core interiors were examined visually by eye and photograph, sometimes by using microphotographs, to observe the level of moisture damage.

Laboratory-fabricated specimens were tested in groups representing the following conditions:

1. Dry, vacuum saturation only;
2. Vacuum saturation followed by 15 hours of 0 F (255.4 K) air freeze followed by 24 hours of 140 F (333.2 K) water bath soak; and
3. Vacuum saturation followed by eighteen 8-hour cycles of 0 to 120 to 0 F (255.4 to 322.0 to 255.4 K) in an air bath.

Specimen interiors were examined visually and by photograph.

Mechanical and visual test data were used to compare core damage to laboratory-fabricated specimen damage.

Mechanical Tests

Tensile split (indirect tension) tests produced tensile strength data and tensile E-modulus data simultaneously. Rates of vertical (compression) deformation and test temperatures were 0.065 in./min. at 55 F (0.165 cm/min. at 285.9 K) and 0.150 in./min.

at 73 F (0.381 cm/min. at 295.9 K). Test times were from 1 to 2 min. per test specimen. A flat loading block was used that did not confine the test specimen during the tensile split test.

Tensile strengths were determined by using the conventional tensile split formula for round test specimens modified for the flattening of the ends of the test specimens at maximum load.

The E-modulus test incorporated a specimen riding device that measured tensile displacement over the test specimen's cross section. These displacements were monitored simultaneously in 5- or 10-second periods with the different loads on the specimens. E-moduli were calculated from these data by extrapolation of the "E-data" to zero test time. Data were recorded easily by 2 operators, 1 working the compression test machine and 1 working an ordinary strain indicator. Figure 1 shows a typical test setup.

A minimum of 4 cores or 4 laboratory specimens per pavement were tested for each of the several moisture conditions and for each of the 2 test temperatures. The test data for the 4 specimens were averaged, and the averages were compared.

REPRESENTATIVE RESULTS AND LABORATORY IMPLICATIONS

Test Results of Pavement Cores

Representative test results of several pavement cores are shown in Figures 2 and 3. The data show tensile strengths and tensile E-moduli for cores in dry and vacuum-saturated conditions. The 55 F (285.9 K) test results are shown; similar trends were obtained at 73 F (295.9 K).

Tensile strengths have a wide range for the pavements shown, and should have some influence, by magnitude only, on the cracking susceptibility of the pavement when asphalt concrete thicknesses are taken into account. Dry tensile strengths are usually higher than saturated tensile strengths. Similar results are observed by using E-moduli.

Tensile tests on dry cores do not show the degree of moisture damage in the cores. There are cores from each of the moisture damage or performance levels shown in Figures 2 and 3 whose test results in the dry condition vary and do not relate to the actual moisture damage level.

Changes (usually relative decreases) of strength and modulus from dry to saturated conditions are much more important to evaluate the extent of moisture damage. For

Figure 1. Tensile split test setup with E-modulus jig.

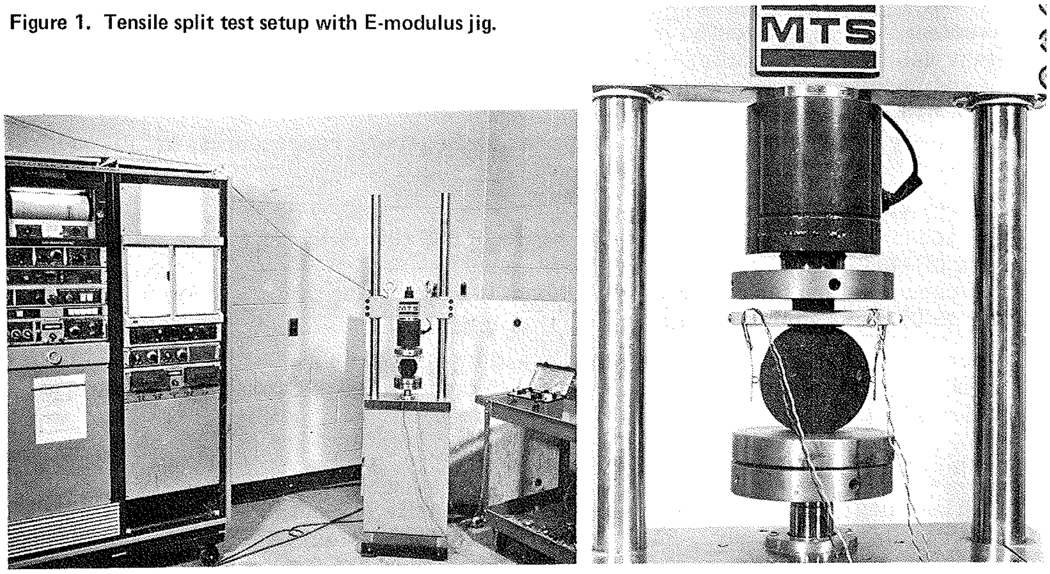


Figure 2. Pavement core tensile strengths.

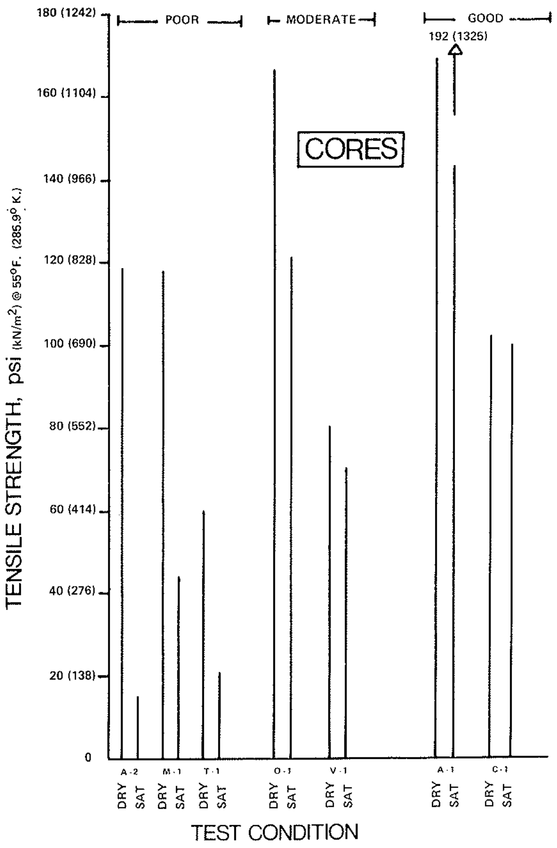
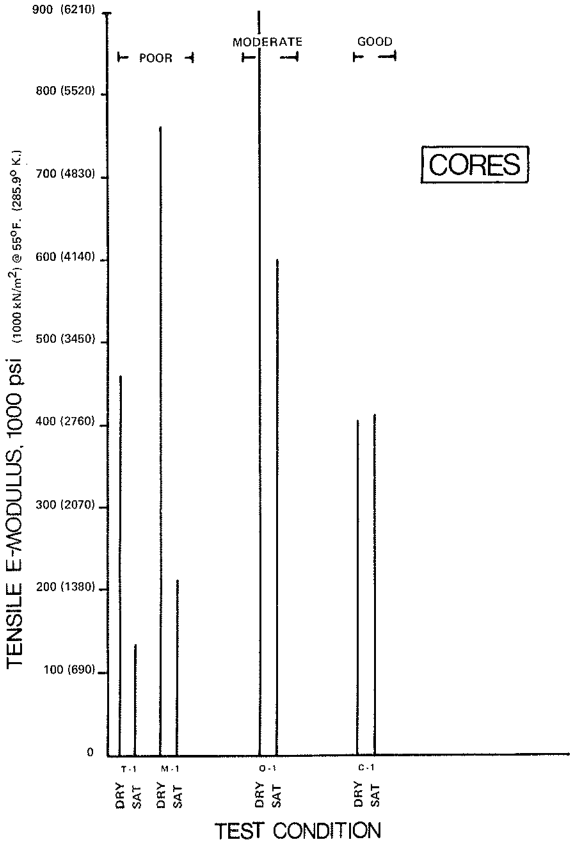


Figure 3. Pavement core E-moduli.



example, test results of cores in the poor level (high moisture damage) show large decreases of strength and modulus magnitudes as compared to other levels of damage. Therefore, moisture damage determined by using these tests is best evaluated by calculating the change in test results between dry and saturated cores. Ratios can be used that are equal to the saturated property magnitude divided by the dry property magnitude. Two ratios are the tensile strength ratio (TSR) and the tensile E-modulus ratio ($M_E R$). For high moisture-damaged pavements, TSRs and $M_E Rs$ could be from 0.1 to 0.4. For low moisture-damaged pavements, the ratios could be from 0.7 to nearly 1.0.

When measuring relative changes, the test temperature of 55 F (285.9 K) is usually more advantageous than 73 F (295.9 K) because the tensile test data magnitudes are greater and thus tend to produce more reliable test results from conventional test machines.

After saturation and testing, all pavement cores opened at the fracture faces showed stripping or softening or both to the relative degree of the change in tensile strength and tensile E-modulus.

Test Results of Laboratory-Fabricated Specimens

Representative test results of a few sets of laboratory-fabricated specimens that duplicate pavement cores are shown in Figures 4 and 5. The data show tensile strengths and tensile E-moduli for laboratory specimens in conditions of dry, vacuum saturation and the thermal-cycle accelerated conditioning of vacuum saturation with 18 cycles of 0 to 120 to 0 F (255.4 to 322.0 to 255.4 K) temperatures. The 55 F (285.9 K) test results are shown; similar trends were obtained at 73 F (295.9 K).

The results in Figures 4 and 5 show the same general trends as were found in the cores. When the specimens became saturated, tensile strengths and E-moduli usually decreased. The accelerated thermal-cycle conditioning, representing the pavement's potential for moisture damage, produced lower strengths and lower E-moduli than did vacuum saturation only for moderate to highly damaged pavements.

Correct matching should show close test-result magnitude comparisons between cores and laboratory specimens in the dry condition, and between cores in the saturated condition and laboratory specimens in the saturated plus thermal cycle condition. Usually the test-result magnitudes for the pavement cores are higher because the asphalt in the cores (pavements) has undergone age-hardening over the years. A comparison for matching purposes is best done by using TSR or $M_E R$ or both.

From the laboratory specimen test data, general estimate of rate of moisture damage can be obtained by observing the relative drop in test data from dry to vacuum-saturated conditions. For example (Fig. 4), the tensile strength drop for pavement A-2 was much greater than the drop for pavement M-1. This indicates that moisture damage built up quickly in A-2. In fact, 1 paving lift of A-2 had to be redone shortly after construction because of a rainstorm.

The laboratory specimens showed similar visual characteristics of moisture damage after thermal cycle conditioning. It is important to open up the cores to observe this damage, which is usually at the tensile-split fracture face. Moisture damage cannot be visually observed at the exterior of laboratory specimens.

The second type of accelerated conditioning, vacuum saturation followed by 0 F (255.4 K) freeze and 140 F (322.2 K) heating, also produced damage in test specimens, but it tended to be somewhat less than that from the thermal-cycle accelerated conditioning and test results appeared to be more scattered.

Predictability

Tensile strength ratios and E-modulus ratios for cores and laboratory specimens were compared at the test temperatures for the different accelerated conditionings to determine predictability. Comparisons for several of the pavements sampled are shown in Figures 6 and 7 for 55 F (285.9 K) test temperatures. In these figures the following should be pointed out:

Figure 4. Laboratory specimen tensile strengths.

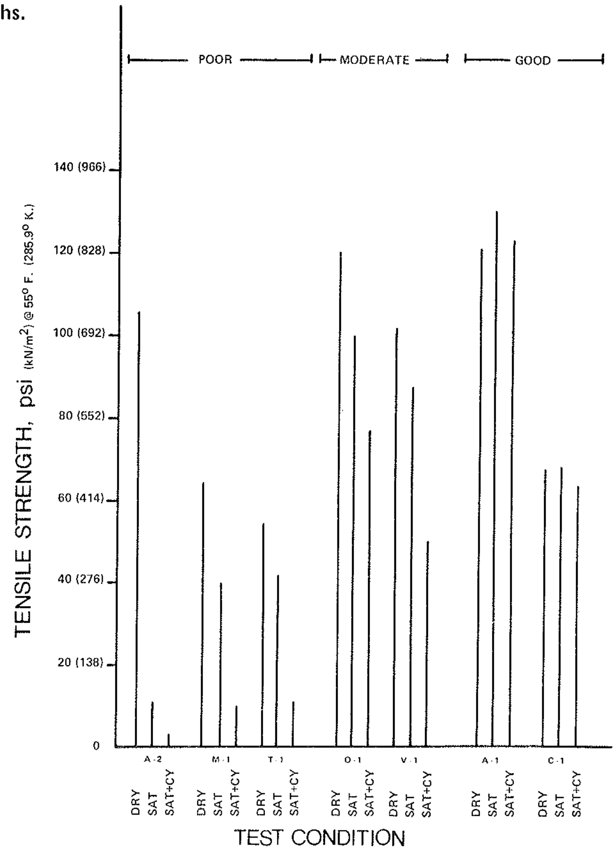


Figure 5. Laboratory specimen E-moduli.

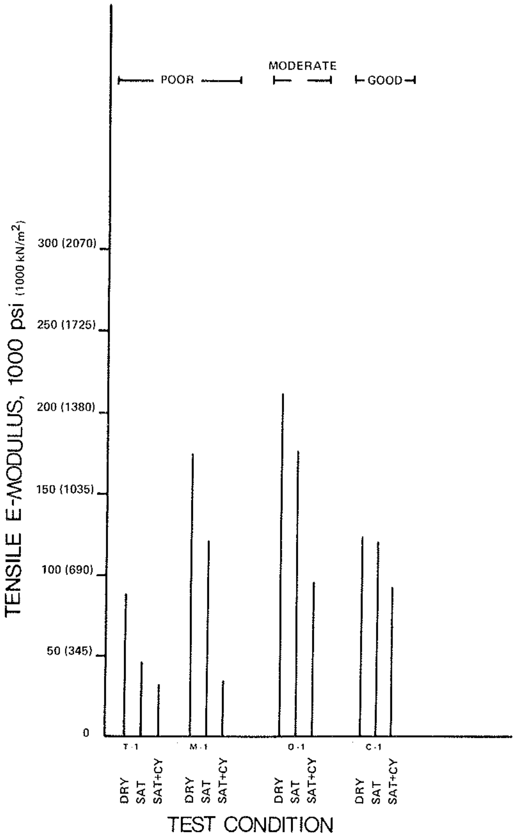


Figure 6. Comparison of core and laboratory tensile strength ratios.

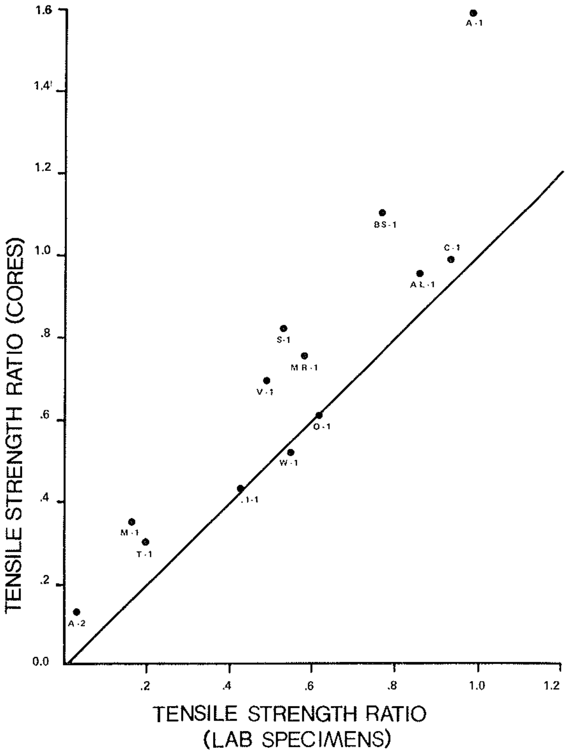
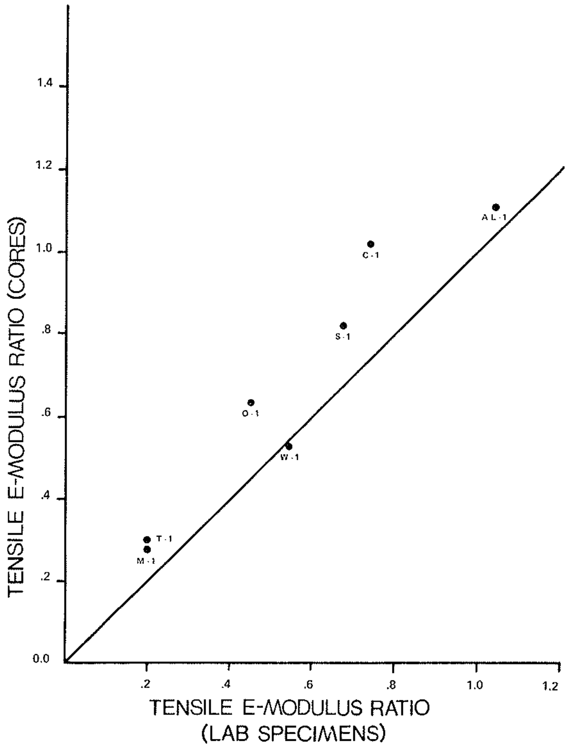


Figure 7. Comparison of core and laboratory E-moduli ratios.



1. Data that plot on the 45-deg line of equality indicate equal matches of ratios for cores and laboratory specimens;
2. Data that plot to the left of the 45-deg line of equality represent overprediction of moisture damage (that is, laboratory specimens after accelerated moisture conditioning have lower ratios than pavement cores);
3. For cores, M_ERs and TSRs equal the vacuum-saturated modulus (strength) divided by the dry modulus (strength); and
4. For laboratory specimens, M_ERs and TSRs equal the vacuum-saturated plus the thermal-cycle conditioning modulus (strength) divided by the dry modulus (strength).

In general, there was overprediction. The laboratory specimen data predicted the moisture damage to cores in 2 or 3 categories. There were no significant underpredictions.

Similar types of ratio plots for test temperatures of 73 F (295.9 K) showed slightly more scatter. Plots of ratios for accelerated conditioning of vacuum saturation followed by a 0 F (255.4 K) freeze and a 140 F (333.2 K) heating underpredicted several of the cores.

Climate does not seem to have an effect on the laboratory conditioning results for moisture damage prediction. For example, when the accelerated moisture conditionings, which contain a freeze element, were applied, the effects were not severe for the cores from zero freezing climates (pavements T-1 and C-1 in Figs. 6 and 7), nor did they have inadequate severity for cores from high freezing climates (pavements M-1 and AL-1 in Figs. 6 and 7). Perhaps the differential thermal expansions (pore pressures and void space changes) and the warm "soak" elements of the accelerated laboratory conditionings combine to accelerate overall temperature change and traffic effects in all climatic locations where sampling was undertaken. It could be possible, however, that climate has an effect on rate of moisture damage along with moisture availability and basic aggregate-asphalt interactive characteristics.

Microphotographic comparison test data will determine which accelerated laboratory conditioning most closely matches cores.

More extensive field evaluations should include the continuous sampling and monitoring of pavements from time of construction. Better information about rate of moisture damage could then be obtained.

KINDS OF APPLICATIONS

Routine Mix Design

Obtaining design asphalt content could be accomplished by studying vacuum-saturated and accelerated-moisture-conditioned specimens having variable asphalt contents. Evaluations could be based on tensile E-modulus, tensile strength, and tensile strain obtained by using an indirect tension test.

Another approach could be to evaluate the moisture-damage resistance of the mix after one obtains the design asphalt content by conventional methods. This would entail making 8 to 12 additional standard-sized test specimens for design asphalt content and evaluating them in the indirect tension mode in dry, vacuum-saturated, and accelerated-moisture-conditioned states. After the results are evaluated, additives and changes in asphalt-aggregate combinations may be found to be needed.

Monitoring Pavements

Cores could be drilled from pavements soon after construction and be subjected to accelerated moisture-damage conditionings. The potential for moisture damage could then be predicted. Every year or 2 thereafter, additional cores could be drilled and tested in a dry, vacuum-saturated condition (without accelerated conditioning) to monitor the rate of moisture damage relative to the predicted potential (maximum) damage. This may help to provide schedule information for pavement maintenance or rehabilitation programs.

Additives and Remedies

Asphalt antistrip additives, filler additives, pavement surface penetrants, and mix variable changes such as voids could be evaluated for effectiveness by a predictive moisture-damage test system. Without an effective test system, predictability of benefits or disbenefits could not be obtained and every remedy used in a pavement could be evaluated only after the pavement was several years old.

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REFERENCES

1. Lottman, R. P. Predicting Moisture-Induced Damage to Asphaltic Concrete. NCHRP Project 4-8(3).
2. Schmidt, R. J., and Graf, P. E. The Effect of Water on the Resilient Modulus of Asphalt-Treated Mixes. Proc. AAPT, Vol. 41, Feb. 1972.